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GB A	2058637	GB A	2023373	GB	1472497
GB	1412300	GB	1250322	GB	1188024
GB	1152366	GB	1113448	GB	0974444
GB	0903910	GB	0827757	GB	0695897
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H2H

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## (54) Generating a plurality of electric discharges

(57) First and second electrodes A1, K1 define a first discharge path and third and fourth electrodes K2, A2 define a second discharge path alongside the first, and the electrodes are electrically connected so that the current flow along the first path is so different from that along the second path that, overall, the discharges repel one another. Electrodes K1 and A2 may be defined by a common member. Applications include cold and hot cathode fluorescent lamps, gas lasers, spark plugs, and submerged arc surface deposition, welding and furnaces.

Also disclosed is electric discharge apparatus in which a first set of electrodes (A12), (A22), (Figure 5), are connected through respective stabilising impedances (R12), (R22) to one side of a power supply, and a second set of electrodes (K12), (K22) are connected through respective stabilising impedances (R32), (R42) to the other side of the supply, stable electric discharger which coalesce being established between the first and second sets of electrodes. Applications include fluorescent and high pressure lamps and gas lasers.

A plasma torch, (Figs 8 to 10), has an electrode holder (23) from which a plurality of electrodes, (E13) to (E63), project, and a pilot electrode (43) is common to more than one of the electrodes. Electrodes (E13) to (E63) are connected to respective rectifiers and inductors to power discharges to a workpiece (63), and are connected to respective D.C. supplies, (V13) to (V63), to power pilot discharges to electrode (43).

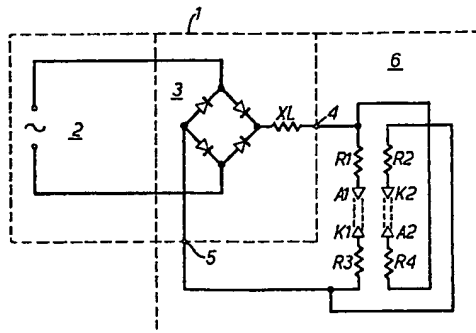


FIG. 1.

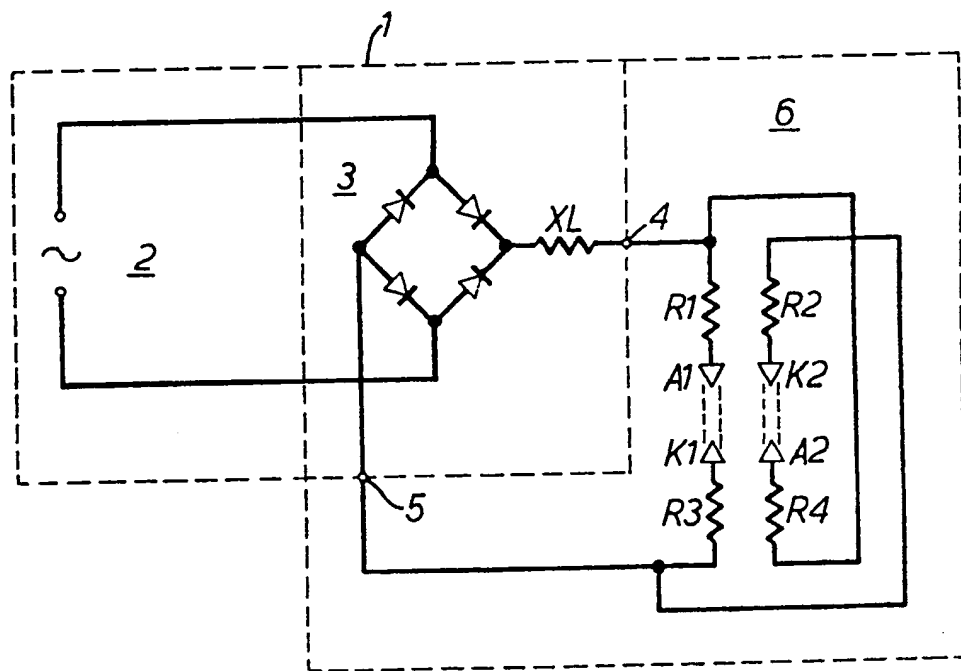


FIG. 1.

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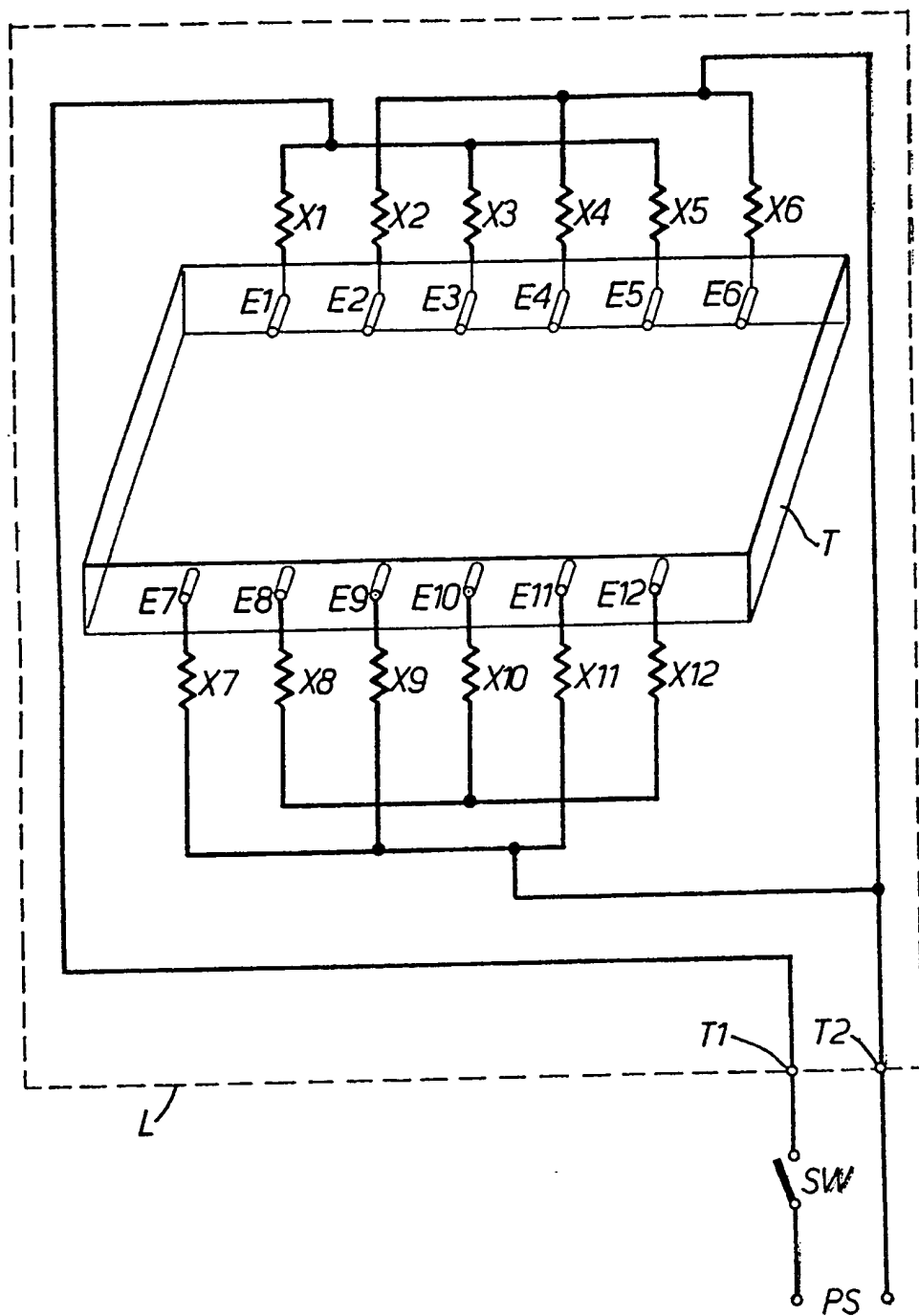


FIG. 2.

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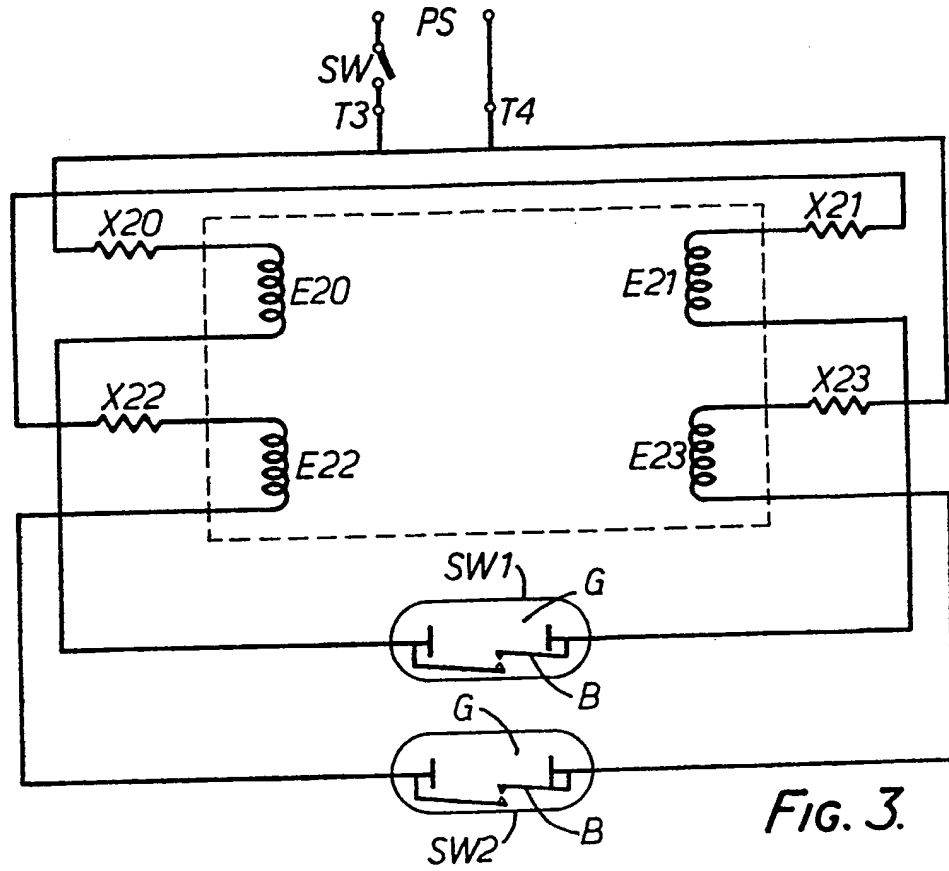


FIG. 3.

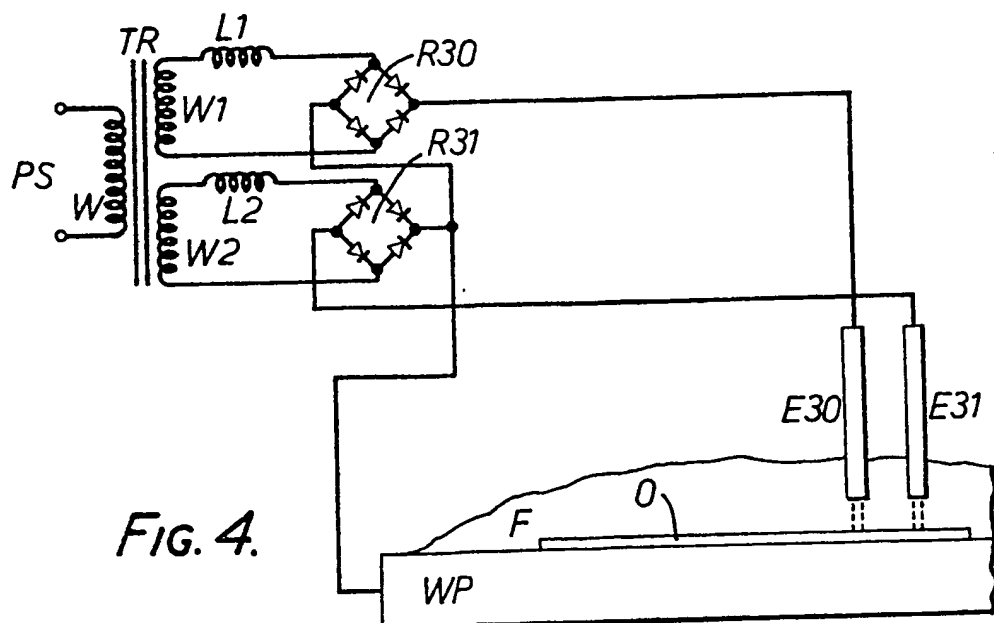


FIG. 4.

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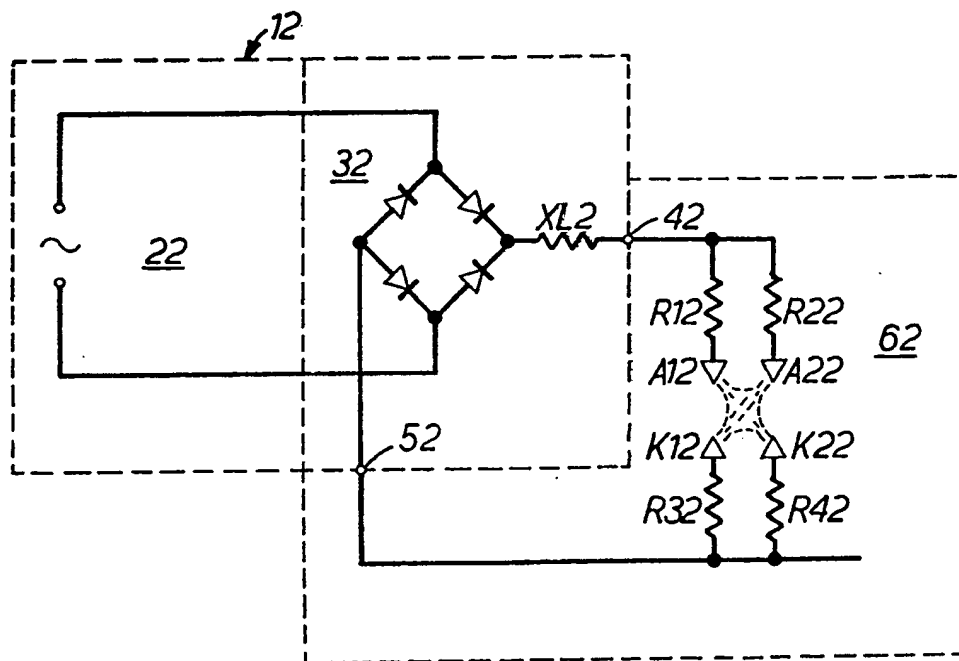


FIG. 5.

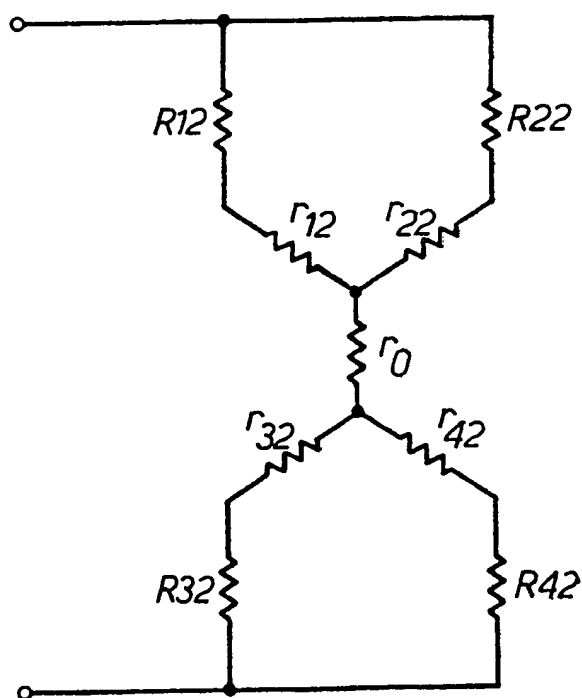


FIG. 6.

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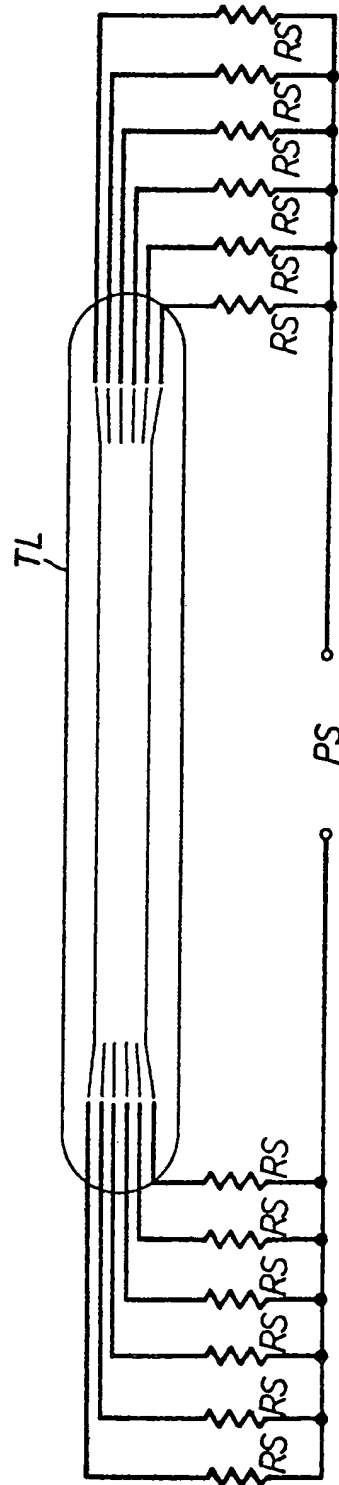


FIG. 7.

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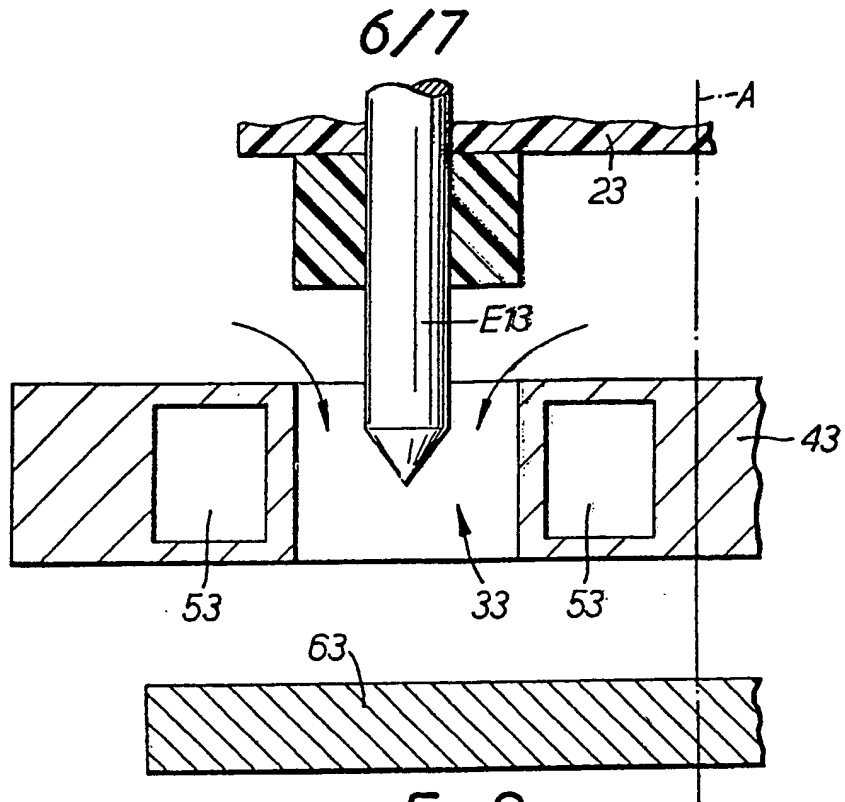


FIG. 8.

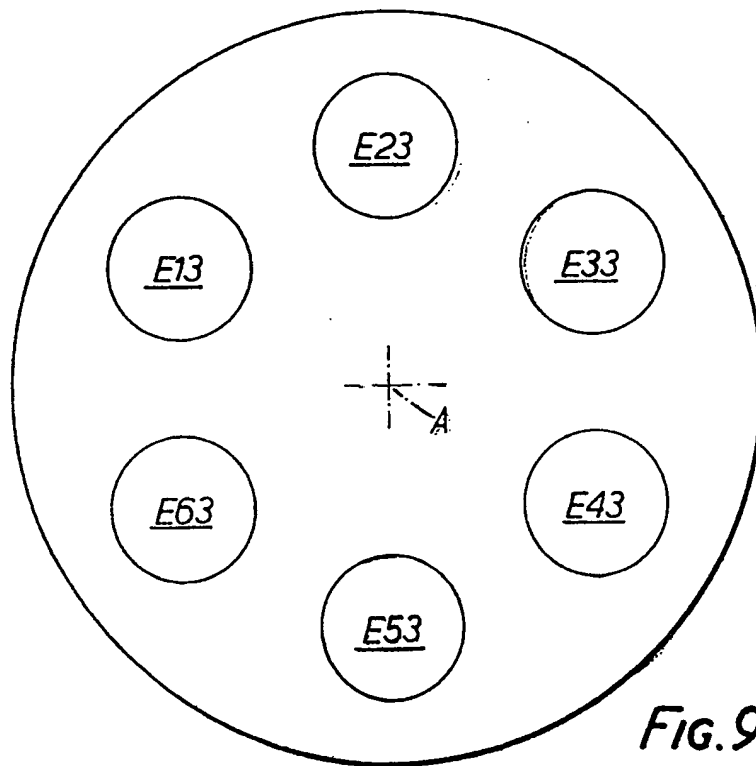


FIG. 9.

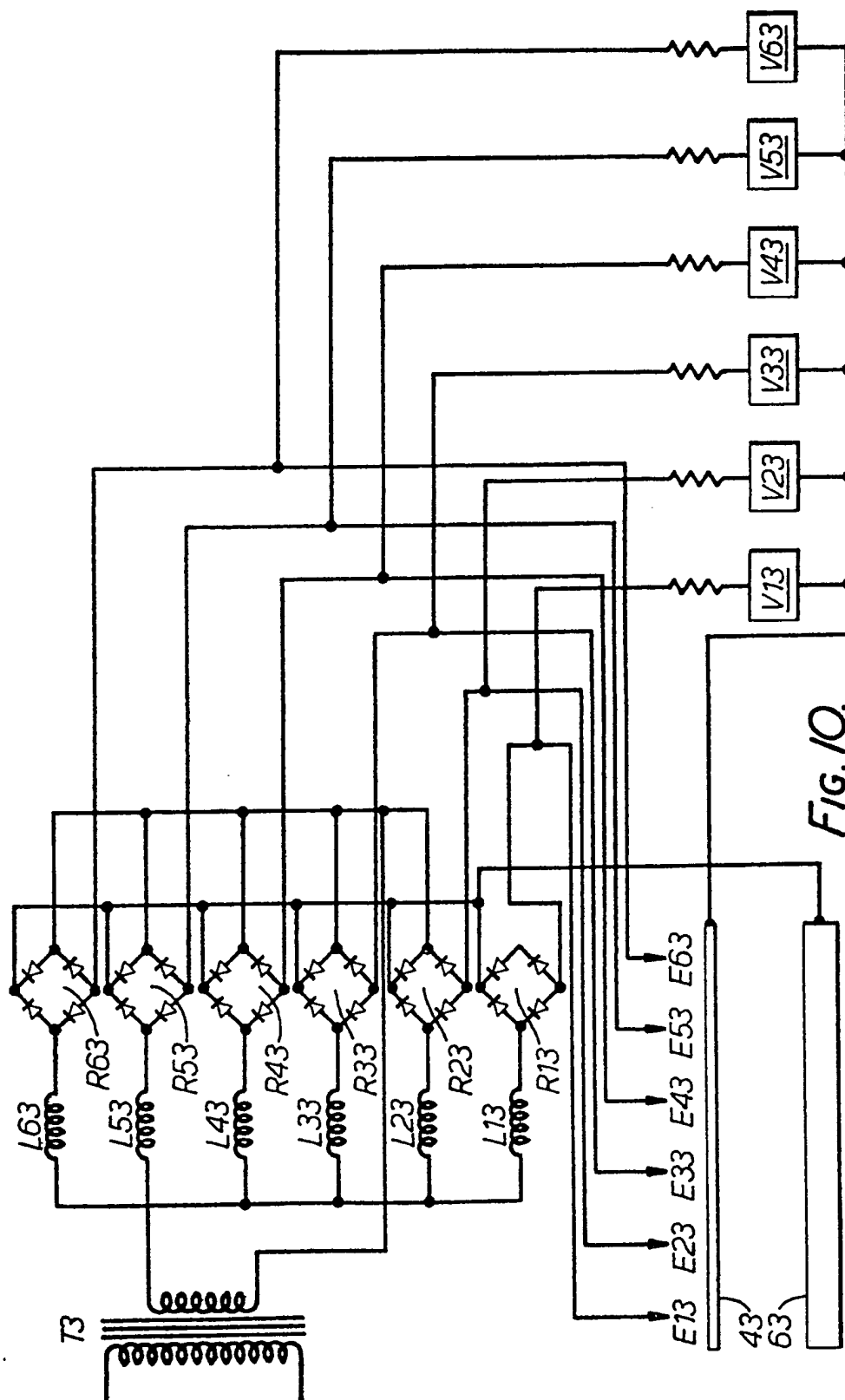


FIG. 10.



## SPECIFICATION

**Improvements in or relating to apparatus and method for generating a plurality of electric discharges**

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This invention relates to electric discharges. More particularly the invention relates, in a first aspect, to arrangements of two or more discharges adjacent to one another, in a second aspect, to stabilization of two or more discharges extending between respective electrodes but coalescing intermediate their ends, and, in a third aspect, to plasma torches.

The term "electric discharge" is used herein in relation to the conduction of electricity by ionised gas and includes processes ranging from, for example, glow discharges of the order of a few milliamps to arc discharges of more than 30,000 A.

Various methods have been used to increase the volume of electric discharges, for example, magnetic fields have been used to rotate discharges between coaxial electrodes and offset the inherent tendency of an electric discharge to constrict due to thermal and electromagnetic effects so as to distribute the energy more uniformly in the space between the electrodes and reduce the power density at the interfaces of the discharge and the electrodes.

There is a mutual attraction between two electric discharges that exist alongside one another when current flows in the discharges are in the same direction and, if they are sufficiently close to one another, the discharges coalesce. At the instant of coalescing the discharges have a central merged portion and four root portions. Such an arrangement has the advantage that the discharge is necessarily less concentrated in the vicinity of the electrodes and also the individual electrode currents are reduced for a given overall discharge current.

If the power for the respective discharges is provided from respective isolated power supplies it is possible to maintain such an arrangement, but the provision of separate power supplies can be disadvantageous.

Although the possibility of generation of coalesced discharges has been known for many years, it is a technique that has not found industrial application. Indeed the normal approach has been to avoid the production of coalesced discharges by maintaining the discharges sufficiently far apart.

Furthermore it has been accepted that in order to create a stable four root coalesced discharge it is essential to have separate power supplies. For example in an article entitled Multielectrode Arc Discharge in the Journal of Applied Spectroscopy, dated 14 February 1967, V. N. Apolitskii when describing a coalesced discharge states that "the basic requirement is always separation of the power supplies which must not have a common point".

The necessity of using separate power supplies when generating coalesced discharges is a serious problem in practice since it raises the costs of the discharge apparatus and also makes the apparatus bulkier and more cumbersome to use.

The central portion of coalesced discharges are concentrated. Thus, the provision of a multi-electrode coalesced discharge is not satisfactory in certain

applications. Also it is not possible to provide such discharges whose ends are closely adjacent to one another and which do not coalesce.

While the design of plasma torches has advanced in various respects over the years there are still limitations in the use of such devices. One such limitation is that the power output of many plasma torches is limited because at currents of the order of 1,000 amps the electrodes evaporate so quickly that their life is impractically short.

In an attempt to overcome this problem it is possible to provide a plurality of plasma torches working together. This however, results in a very bulky device and, with each torch having its own power supply, makes the device very expensive.

In a first aspect, it is an object of the invention to provide an electric discharge apparatus and a method of generating electric discharges that in certain respects overcomes at least some of the disadvantages described above.

In a second aspect, it is an object of the invention to provide stabilization of two or more discharges extending between respective electrodes but coalescing intermediate their ends and generated from a common power supply.

In a third aspect, it is an object of the invention to provide an improved plasma torch capable of operating with high discharge currents.

In a first aspect, the invention provides an electric discharge apparatus including first and second electrodes defining a first discharge path, and third and fourth electrodes defining a second discharge path alongside the first discharge path, wherein the electrodes are electrically connected such that, in use, the current flow of a discharge along the first path is so different from the current flow of a discharge along the second path that, overall, the discharges repel one another.

In certain circumstances the second and fourth electrodes may be defined by a common member.

The first and second discharge paths may be within coalescing range.

The discharge paths are "within coalescing range" as hereby defined if they are sufficiently close to one another that discharges having current flows in the same direction would coalesce with one another.

In the case of direct currents, the current flow in the first discharge path is arranged to be in the opposite direction to the current flow in the second discharge path. In the case of alternating currents, the current flow in the first discharge path may be arranged to be of opposite phase to the current flow in the second discharge path, or the current flows may merely be sufficiently out of phase that the overall effect is that the discharges repel one another.

The first and third electrodes may be adjacent one another and the second and fourth electrodes may be adjacent one another. Each of the first and fourth electrodes may be connected through a respective impedance to a common terminal and each of the second and third electrodes may be connected through a respective impedance to another common terminal, the common terminals being for connection to a power supply. In the case where the second and fourth electrodes are common the impedance associ-

ated with these electrodes may be omitted or shared. In this arrangement the apparatus is operated from a common power supply; if desired, however, the apparatus may be operated with each discharge path  
5 connected to a separate power supply.

A respective impedance may be connected to each electrode in the power supply path to that electrode. The impedances prevent discharges between the first and third electrodes or the second and fourth elec-  
10 trodes. The impedances may be resistors and/or inductors though capacitance may also be included. The impedances may be all of substantially the same value.

One or more further discharge paths defined by  
15 further electrodes may be arranged alongside the first and second discharge paths.

The apparatus may be embodied in discharge lamps such as fluorescent lamps, lamps used as a source of ultra violet radiation, decorative or display  
20 lighting or a gas laser. In the case where the second and fourth electrodes are defined by a common member the apparatus may be embodied in a submerged arc welding apparatus or other welding equipment, or in an electric arc furnace. The apparatus  
25 may also be embodied in a spark plug.

Also in a first aspect, the invention provides a method of generating discharges including the steps of generating a first discharge, and generating a second discharge alongside the first discharge,  
30 wherein the current flow in the first discharge is so different from the current flow in the second discharge that, overall, the discharges repel one another.

The first and second discharges may be within coalescing range.

35 The method may include generating further discharges alongside the first and second discharges.

In a second aspect, the invention provides an electric discharge apparatus including first and second terminals for connection to a power supply, a  
40 first set of electrodes comprising two or more electrodes, each electrode of the first set being connected through a respective first impedance to the first terminal, and a second set of electrodes comprising two or more electrodes, each electrode of the  
45 second set being connected through a respective impedance to the second terminal, the first and second sets of electrodes being spatially arranged such that, when, in use, the first and second terminals are connected across a power supply, stable electric  
50 discharges which coalesce are generated between respective electrodes of the first and second sets.

In order for the discharges to be stable the impedances are, preferably, each above a minimum value of the same order of magnitude as the impedance of the discharge during stabilized operation.  
55 Such a minimum value can readily be determined for any particular discharge apparatus. In the case of a discharge apparatus having two electrodes of the first set side by side and two electrodes of the second set  
60 side by side with supply voltages of 80V-100V and discharges of 15 mm length with discharge currents in the range of 10A-20A, resistors of less than 1Ω resistance are suitable. The impedance may be increased as much as desired above the minimum  
65 level but at the expense of increased power dissipa-

tion in the impedance.

The impedances may be resistors and/or, inductors though capacitance may also be included.

70 Preferably the first impedances are of substantially the same value and the second impedances are also of substantially the same value. The value of the first impedances and the value of the second impedances are also preferably the same.

Impedance adjusting means may be provided for  
75 adjusting the discharge currents. Such means may comprise an adjustable impedance connected between the power supply and the first or second terminal but alternatively the adjusting means may comprise means for adjusting the impedance of each  
80 of said first and second impedances. Preferably the adjusting means is arranged to adjust the impedance of each of the first impedances and each of the second impedances equally.

The power supply itself may have impedance which  
85 is shared with each electrode. If this is large compared to the individual stabilizing impedances the discharges will behave in the same way as discharges supplied from a single source and without individual stabilization, and one or more discharge roots will be  
90 extinguished.

The apparatus may be embodied in discharge lamps such as fluorescent lamps, lamps used as a source of ultra violet radiation, decorative or display  
lighting, or a gas laser.

95 Also in a second aspect, the invention provides a method of generating two or more electric discharges extending between respective electrodes but coalescing intermediate their ends, the method including the following steps:

100 providing a first set of electrodes comprising two or more electrodes,  
providing a second set of electrodes comprising two or more electrodes,  
connecting each electrode of the first set through a  
105 respective impedance to a common source of a first potential, and  
connecting each electrode of the second set through a respective impedance to a common source of a second potential,

110 the first and second sets of electrodes being spatially arranged such that stable electric discharges which coalesce are generated between respective electrodes of the first and second sets.

The first and second potentials provide a voltage  
115 across the electrodes which may be an A.C. voltage or a D.C. voltage. One of the potentials may be earth potential.

In a third aspect, the invention provides a plasma torch comprising an electrode holder from which a  
120 plurality of electrodes electrically insulated from one another project and a pilot electrode common to more than one of said plurality of electrodes.

By providing a plurality of electrodes in a single torch a plasma torch capable of handling high  
125 discharge currents is provided that is both compact and economical. Since a common pilot electrode is provided the whole of the electrode can easily be cooled by a single cooling system.

Preferably a single pilot electrode is provided  
130 common to all of said plurality of electrodes.

The pilot electrode may have separate portions associated with respective ones of said plurality of electrodes but, in this case, the separate portions are electrically connected together.

5 In one embodiment of the invention a respective power supply is provided for initiating a discharge between each of said plurality of electrodes and the pilot electrode. On the other hand a common power supply is provided for supplying current to said  
10 plurality of electrodes. The common power supply is connected through respective impedances to each of said plurality of electrodes. Said plurality of electrodes may be surrounded by a common nozzle. It might be thought that the provision of a common pilot electrode would cause difficulties in initiating the discharges but by providing a separate power supply to  
15 initiate each discharge these difficulties are overcome.

The number of electrodes in said plurality may be between five and thirty. Since each electrode can carry  
20 a current of the order of 1,000 amps, it is therefore possible with thirty electrodes to have a total discharge current of 30,000 amps.

By way of example, embodiments of the invention will now be described with reference to the accompanying drawings, of which:

25 Figure 1 is a diagram of an electrical discharge apparatus embodying the invention;

Figure 2 shows a cold cathode fluorescent lamp embodying the invention;

30 Figure 3 shows a hot cathode fluorescent lamp embodying the invention;

Figure 4 shows a submerged arc welding apparatus embodying the invention;

35 Figure 5 is a diagram of another electrical discharge apparatus embodying the invention;

Figure 6 shows the equivalent circuit for part of the apparatus of Figure 5;

40 Figure 7 shows a discharge lamp embodying the invention;

Figure 8 is a sectional side view of part of a plasma torch;

45 Figure 9 is a simplified sectional plan view of the torch illustrating the relative positions of the electrodes; and

Figure 10 is a diagram of an electrical circuit including the plasma torch of Figures 8 and 9.

Referring to Figure 1 a power supply 1 consisting of an A.C. voltage supply 2, a bridge rectifier 3 and an inductive impedance XL is connected to terminals 4  
50 and 5 of a discharge apparatus 6. The discharge apparatus has a first anode A1 associated with a first cathode K1 and defining a first discharge path and a second anode A2 associated with a second cathode K2 and defining a second discharge path alongside the  
55 first path and within coalescing range of the first path. The first anode A1 and second cathode K2 are adjacent one another and similarly the second anode A2 and the first cathode K1 are adjacent one another. Each anode A1, A2 is connected through a respective  
60 resistor R1, R4 to the terminal 4 while each cathode K1, K2 is connected through a respective resistor R3, R2 to the terminal 5. The resistors R1, R2, R3 and R4 are typically all of the same value.

The voltage generated by the power supply is  
65 sufficient to create one discharge between the

cathode K1 and anode A1 and another discharge between the cathode K2 and anode A2. The separation of the discharges is sufficiently small that they interact and, if the current flows in the discharges were in the  
70 same direction, they would attract one another and coalesce. However since the current flows are in opposite directions the discharges repel one another and do not coalesce.

Because electric discharges generally have a negative dynamic resistance characteristic, that is as the current increases the resistance of the discharge decreases, the generation of two discharges from a common power supply is inherently unstable since an increase in the current in one discharge will tend to  
75 reduce the resistance of that discharge path tending in turn to increase further the current through the discharge. As the current in one discharge increases so the current in the other discharge is reduced, since the currents are derived from a common power  
80 supply, until all the current is carried in one discharge and the other discharge is extinguished.

In the circuit of Figure 1, however, the resistors R1, R2, R3 and R4 are provided and if these impedances are sufficiently large, then a drop in the resistance in one discharge will still tend to lead to an increase in current in the discharge but, because of the resistors, the voltage across the discharge path is also reduced and the current in the discharge is limited. Any increase in the current in the discharge produces an increased potential drop across the associated resistors which overrides any reduction in the potential drop across the discharge path. Accordingly the current remains evenly distributed between the two discharges.

100 It will be noted that while the discharges are described as extending between anode A1 and cathode K1 and between anode A2 and cathode K2 there are also potential discharge paths between anode A1 and cathode K2 and also between anode A2 and cathode K1. The provision of a respective resistor for each electrode of the apparatus ensures that the resistance connected in these potential discharge circuits (not including the resistance of the discharge path) is as great as that connected in the intended  
105 discharge circuits, so that provided the potential discharge paths are longer than the intended discharge paths, there are no discharges along these potential discharge paths.

There are other ways of preventing discharges along these potential discharge paths. For example, if an A.C. supply is being used the circuit arrangement shown in Figure 1 may be modified so that the phases of the voltages applied to adjacent discharge paths are out of phase sufficiently to prevent adjacent discharges coalescing but not in direct anti-phase relationship. Consequently the highest potential at anode A1 does not occur at the same time as the lowest potential at cathode K2 so that the peak potential differences along these potential discharge paths is less than the peak potential differences across the intended discharge paths.

Another way of preventing discharges along the potential discharge paths is to arrange for the spacing of the anode A1 and cathode K2 from the cathode K1 and the anode A2 to be adjustable. This spacing can  
130

then be reduced to a minimum to initiate the discharges and then drawn out to the desired spacing once the discharges have been ignited (it will be appreciated that a much larger electric field is required to ignite a discharge than to maintain the discharge once ignited). Another alternative is to introduce an ignition electrode partway along each of the intended discharge paths.

In one particular example of the invention the adjacent electrodes were separated from each other by 10 mm, and the discharge paths were both of length 10 mm. Resistors R1, R2, R3 and R4 were each of resistance 5Ω and with this arrangement an average rectified open circuit voltage of 110 V was applied across the terminals 4, 5 generating a total discharge current of about 10 A, with a discharge voltage of about 60 V.

In the example described above there are only two discharge paths but it is of course possible to add further electrodes alongside those shown so that more than two adjacent discharge paths are provided.

Figure 2 shows a cold cathode fluorescent lamp L having multiple discharge paths. Instead of having a conventional tube of circular cross-section, the tube T is of flat cuboidal shape which in itself is advantageous since, for example, it enables a large illuminated surface to be defined by the lamp. It should be understood, however, that a tube of circular or other cross-section could be employed. In the example shown, there are six electrodes E1 to E6 provided on one of the longer sides of the lamp, and another six electrodes E7 to E12 provided on the other side of the lamp. The electrodes E1 and E7, E2 and E8, E3 and E9 etc define respective adjacent discharge paths. A respective impedance X1, X2, X3 . . . X12 is connected between each electrode E1, E2, E3 . . . E12 and one of the terminals T1 and T2 connected through a switch SW to the mains power supply PS. The electrodes E1, E3, E5, E8, E10 and E12 are connected to terminal T1 while the other electrodes are connected to terminal T2. The impedances X1, X2, X3 etc are preferably all the same and may include a resistive and/or an inductive component.

When the switch SW is closed respective discharges are generated between the electrodes E1 and E7, E2 and E8, E3 and E9, E4 and E10, E5 and E11, and E6 and E12. Each discharge is of opposite phase to the adjacent discharge(s) and therefore the discharges do not coalesce. Since the discharges are spread over the tube, the fluorescent coating on the tube provides a light output distributed reasonably evenly over the surface of the tube. Also for a given total discharge current, the individual electrode currents are reduced to one sixth of those in a single discharge tube, so that a longer electrode life, or alternatively a greater output can be achieved.

Although in the schematic illustration in Fig. 2 the impedances are shown connected externally of the tube, it should be understood that the impedances could be provided inside the tube.

Although in relation to Figure 2, no particular technique for initiating the discharges has been described, it should be understood that any suitable one of the techniques described elsewhere in this specification may be employed.

Figure 3 shows an electric circuit diagram for a hot cathode fluorescent lamp having two discharge paths. One discharge path is defined by electrodes E20 and E21 and another adjacent discharge path by electrodes E22 and E23. A respective impedance X20, X21, X22 and X23 having a large inductance is connected between one terminal of each electrode and one of terminals T3 and T4 connected through a switch SW to mains power supply PS. The impedances X20, X21, X22 and X23 are all the same.

The other terminals of the electrodes E20 and E21 are connected together through a starting switch SW1 and similarly the other terminals of the electrodes E22 and E23 are connected together through a starting switch SW2. The starting switches SW1 and SW2 are identical and each comprise a glow lamp G and an associated bimetallic switch B in the glow lamp and connected in parallel with the discharge path of the glow lamp. The switch B is open at room temperature and closes upon heating.

When the switch SW is closed glow discharges are generated in the lamps G. Considering for example the circuit with electrodes E20 and E21, an electric circuit is formed from the terminal T3 through the impedance X20, the electrode E20, the glow discharge in lamp G, the electrode E21 and the impedance X21 to the terminal T4. The glow discharge heats the bimetallic switch which closes, short circuiting the glow discharge and causing a larger current to flow through the electrodes making them incandescent. The bimetallic switch cools and then opens interrupting the electric circuit and, because of the inductive impedances X20 and X21, creating a very high voltage across the electrodes thereby creating a discharge therebetween. Discharges do not occur between adjacent electrodes, for example between the electrodes E20 and E22 because the voltage available to generate a discharge between these electrodes is less and the inductive impedance X22 also acts to oppose the voltage between these electrodes. The glow discharge lamp which is now shunted by the discharge between the electrodes E20 and E21 remains extinguished and the bimetallic switch therefore remains open. It will be understood that the circuit with electrodes E22 and E23 operates in exactly the same manner.

It should be understood that the inductive impedances serve the following functions, namely to provide a very high voltage to ignite a discharge, to stabilize the discharge and to oppose the voltage between adjacent electrodes during ignition of a discharge. These functions may be served by one or more components.

Although in Figure 3, only two adjacent discharge paths are shown it will be understood that further discharge paths, for example six as in Figure 2, may be provided.

The invention may also be embodied in discharge lamps such as fluorescent lamps, lamps used as a source of ultra violet radiation, decorative or display lighting or a gas laser.

In the embodiments of the invention described so far each of the adjacent discharges terminates in a respective electrode. In certain applications, however, it may be desirable for two discharges to terminate at a

common electrode. Figure 4 shows an arrangement of this kind which may be used in submerged arc surface deposition for example. A power supply PS is connected to the primary winding W of a transformer TR which has secondary windings W1 and W2 connected through inductors L1 and L2 respectively to rectifiers R30 and R31 respectively. The positive output of rectifier R31 and the negative output of rectifier R30 are connected to a workpiece WP while the negative output of rectifier R31 is connected to an electrode E31 and the positive output of rectifier R30 is connected to an electrode E30. The electrodes E30 and E31 are closely adjacent one another. The inductors L1 and L2, act as smoothing inductors and also stabilize the discharges between the electrodes E30 and E31 and the workpiece.

The tips of the electrodes E30 and E31 are submerged in powder flux F on top of the workpiece WP and discharges are formed between the tips of the electrodes and the workpiece causing the electrodes to melt under the flux and be deposited on the workpiece at D. It will be seen that the electric circuit arrangement provides for discharge currents of opposite phase in the adjacent paths so that the discharges repel one another and remain separate. The use of a plurality of discharges enables surface deposition over a given area at a faster rate, which is of particular advantage where the given area is large.

Again, although only two electrodes are shown it would be possible to use more than two electrodes.

Apart from submerged arc surface deposition the common electrode arrangement could be used in other welding applications including submerged arc welding and could also be used in an arc furnace. In this case, an advantage of the arrangement would be that since the discharges would repel one another they would be spread over a large region.

A further application of the invention would be in an electric spark plug. In this case the discharge paths could be defined by separate electrodes or a common electrode could define one end of each of the discharge paths.

Referring now to Fig. 5 a power supply 12 consisting of an A.C. Voltage supply 22, a bridge rectifier 32 and an inductive impedance XL2 is connected to terminals 42 and 52 of a discharge apparatus 62. The discharge apparatus has a pair of anodes A12, A22 defining a first set of electrodes and a pair of cathodes K12, K22 defining a second set of electrodes. Each anode A12, A22 is connected through a respective resistor R12, R22 to the terminal 42 and each cathode K12, K22 is connected through a respective resistor R32, R42 to the terminal 52.

The voltage generated by the power supply 12 is sufficient to create one discharge between the cathode K12 and anode A12 and another discharge between the cathode K22 and anode A22. However the separation of the discharges is sufficiently small that they interact and attract one another so that the discharge consists of a central region common to both discharges and peripheral regions adjacent to each electrode.

Fig. 6 shows the equivalent circuit for the discharge arrangement of Fig. 5. Resistance  $r_o$  is the resistance of the discharge path common to both discharges

while resistances  $r_{12}$ ,  $r_{22}$ ,  $r_{32}$  and  $r_{42}$  are resistances of the discharge paths between the common discharge path and the resistors R12, R22, R32 and R42 respectively.

As already mentioned, electric discharges generally have a negative dynamic resistance characteristic, that is as the current increases the resistance of the discharge decreases. Thus the value of the resistances  $r_{12}$ ,  $r_{22}$ ,  $r_{32}$  and  $r_{42}$  are variable and dependent upon the current carried by the discharge.

The manner in which stability of the discharge is obtained can be understood by considering the operation of the upper branches of the circuit shown in Fig. 6 and making the simplifying approximation that the junction of resistances  $r_{12}$  and  $r_{22}$  is at constant potential.

If the stabilizing resistors R12 and R22 are not employed so that R12 and R22 are zero then with a symmetrical arrangement of electrodes the discharge paths represented by resistances  $r_{12}$  and  $r_{22}$  will be the same length and  $r_{12}$  and  $r_{22}$  will be equal so that equal currents flow through each path. If, however, owing to a change in, for example, a physical property of a discharge path, the resistance  $r_{12}$  drops slightly this will lead to an increase in current through the resistance  $r_{12}$  which in turn will further reduce the resistance  $r_{12}$  as a result of the negative dynamic resistance of the discharge. As the resistance  $r_{12}$  drops so the current through resistance  $r_{22}$  decreases and accordingly the resistance  $r_{22}$  increases. Eventually the discharge of resistance  $r_{22}$  is extinguished and all the current passes through the alternative discharge path.

On the other hand, with sufficiently large resistors R12 and R22 a drop in the resistance  $r_{12}$  owing to a change in a physical property of the discharge path leads to an increase in current through this discharge path but because of the resistor R12, the voltage across the discharge path is also reduced and the increase in current through resistance  $r_{12}$  is limited. Any increase in the current through the resistance  $r_{12}$  produces an increased potential drop across the resistance R12 which overrides any reduction in the potential drop across resistance  $r_{12}$ . Accordingly the current remains distributed between the discharge paths of resistance  $r_{12}$  and  $r_{22}$ .

From the description above it will be clear that it is necessary to provide a respective resistance for each electrode of the apparatus of Fig. 5 in order to provide a stable discharge.

The inductive impedance XL2 operates to smooth the output of the rectifier 32 and also opposes changes in the discharge current thereby assisting in stabilization of the discharge.

In one particular example of the invention the anodes A12 and A22 were separated from each other by 10 mm, the cathodes K12 and K22 were separated from each other by 10 mm, and the anodes were separated from the cathodes by 10 mm, with the cathodes K12 and K22 vertically below the anodes A12 and A22 respectively. Resistors R12, R22, R32 and R42 were each of resistance 5Ω. With this arrangement an average rectified open circuit voltage of 110 V was applied across the terminals 4, 5 generating a total discharge current of about 10 A, with a discharge

voltage of about 60 V.

Although in the described embodiment the power supply generates full wave rectified direct current, the discharge apparatus may be used with a constant voltage D.C. supply or with an A.C. supply.

It should be understood that additional anodes A32, A42 etc. with respective stabilizing resistors may be added in parallel with anodes A12 and A22 and similarly additional cathodes with respective stabilizing resistors may be added in parallel with cathodes K12 and K22. It is not essential that the number of anodes and cathodes be the same: for example four anodes and two cathodes could be provided.

If it is desired to regulate the discharge current then the resistors R12, R22, R32 and R42 may be made variable and connected to a common control which adjusts their resistance equally.

Apparatus of the kind shown in Fig. 5 may be used in a variety of applications but one particular application in which it is of particular value is in a high pressure discharge lamp. Figure 7 shows schematically the electrode arrangements for such a lamp TL. In place of the usual single anode and cathode at respective ends of the lamp a plurality of anodes and cathodes are provided. In the example shown in Fig. 7 six cathodes and six anodes are provided, each electrode having a stabilizing resistance RS connected between it and a common power supply PS. At present discharge lamps can be limited in current rating by the rate of evaporation of the electrode material. With the arrangement shown in Fig. 7, however, the individual electrode currents are limited to one sixth of the total discharge current so that a longer electrode life or alternatively a greater output can be achieved.

No specific arrangement for initiating the discharges has been described but it will be understood that conventional techniques may be employed. One method of initiating the discharges is to introduce an ignition electrode partway along each of the intended discharge paths; another method is to use an inductive starting circuit.

Although in the schematic illustration in Fig. 7 the stabilizing resistances RS are shown connected externally of the discharge lamp, it should be understood that the resistances could be provided inside the tube.

Other applications of apparatus of the kind shown in Fig. 5 may be found in discharge lamps such as fluorescent lamps, lamps used as a source of ultra violet radiation, decorative or display lighting or a gas laser.

Figures 7 to 9 showing a plasma torch embodying the invention are schematic and are provided to illustrate novel features of the plasma torch. Other features known to those skilled in the art from conventional design techniques of plasma torches are not illustrated.

Referring to Figures 8 and 9 the plasma torch illustrated has six tungsten electrodes E13, E23, E33, E43, E53 and E63 equiangularly spaced about a central axis A. The electrodes are held in an insulated holder 23 from which they each project downwardly into a respective nozzle aperture 23 of an electrically conducting member 43 which is provided with water cooling channels 53. In use gas, for example argon, is supplied to the torch and flows through the apertures

33 past the electrodes. An electrically conducting workpiece 63 which may, for example, in the case of a plasma furnace be scrap steel to be melted is located under the plasma torch.

Figure 10 shows the electrical supply arrangement for the torch. Each of the electrodes E13, E23, E33, E43, E53 and E63 is connected through a respective rectifier R13, R23 . . . R63 and inductance L13, L23 . . . L63 to the secondary winding of a transformer T3, whose secondary winding, in this example, is able to provide sufficient current to cater for the high discharge currents at each of the electrodes E13, E23 . . . E63 during full operation of the torch. Thus for example the secondary winding may have a current rating of the order of 6,000 amps in this example. Typically the rectifiers R13, R23 . . . R63 and inductors L13, L23 . . . L63 are all the same.

A respective D.C. voltage supply V13, V23 . . . V63 in series with a current limiting impedance X13, X23 . . . X63 is also connected between each of the electrodes E13, E23 . . . E63 and the member 43. The D.C. voltage supplies are relatively low current (for example about 100A) and high voltage (for example 200V) supplies and are provided to initiate and maintain the pilot discharges between each of the electrodes E13, E23 . . . E63 and the member 43.

From the description above the operation of the device will be generally clear to those skilled in the art and will not be described in detail here. The respective pilot discharges are generated from separate supplies and thus there are no difficulties in maintaining the pilot discharges in parallel to one another. On the other hand the main discharges occurring during full operation of the torch are generated from a single supply and this would conventionally be considered an unstable arrangement. Because electric discharges, as already mentioned, generally have a negative dynamic resistance characteristic, that is as the current increases the resistance of the discharge decreases, the generation of two or more discharges from a common power supply is inherently unstable since an increase in the current in one discharge will tend to reduce the resistance of that discharge path, tending in turn to increase further the current through the discharge. As the current in one discharge increases so the current in the other discharge is reduced, since the currents are derived from a common power supply, until all the current is carried in one discharge and the other discharge is extinguished.

In the circuit of Figure 10, however, the inductors L13, L23 . . . L63 are provided and if these are sufficiently large, than a drop in resistance in one discharge will still tend to lead to an increase in current in the discharge but, because of the inductors, the voltage across the discharge path is also reduced and the current in the discharge is limited. Any increase in the current in the discharge produces an increased voltage drop across the associated inductor which overrides any reduction in the voltage across the discharge path. Accordingly the current remains evenly distributed between the discharges.

Since a common nozzle defining member 43 is provided, considerable and important reductions in the size and complexity of the device are obtained

compared with employing six separate plasma torches.

In the example described the member 43 has respective apertures for each electrode E13, E23 . . .

5 E63 so that a separate nozzle is defined for each electrode. An alternative arrangement is to provide a single nozzle around the outside of all the electrodes E13, E23 . . . E63. In this respect it should be noted that whilst it is often a common feature of a conventional  
10 plasma torch that the nozzle is severely constricted this is not a necessary feature of the present invention. For very high operating temperatures, for example, 20,000°C it is of course necessary to concentrate the heat generated by the discharge in a small volume but  
15 in many applications of the present invention it is the enthalpy generated by the torch that is important and the torch can be operated with a lower temperature output.

In the drawings the voltage supplies V13, V23 . . . V63 are shown completely separate from one another. It should be understood that the voltage supplies may for practical purposes be derived from a common power source provided that they are sufficiently electrically isolated from one another as to behave like  
25 separate supplies.

A plasma torch embodying the invention may be used in many different applications. The use of the torch in a furnace to produce steel has already been mentioned. The torch may also be used as a non-consumable electrode in a vacuum arc furnace, in the reduction of ferro alloys or in any other application  
30 where a high power plasma torch is required, for example cutting, welding or spraying.

The circuit arrangement of the torch may be such that the current flows in the discharges are not all in the same direction and discharges having opposing current flows repel each other. This would have the advantage of spreading the discharges.

#### CLAIMS

40 1. An electric discharge apparatus including first and second electrodes defining a first discharge path, and third and fourth electrodes defining a second discharge path alongside the first discharge path, wherein the electrodes are electrically connected such  
45 that, in use, the current flow of a discharge along the first path is so different from the current flow of a discharge along the second path that, overall, the discharges repel one another.

2. An apparatus as claimed in claim 1 in which the second and fourth electrodes are defined by a common member.

3. An apparatus according to claim 1 or 2 in which the first and second discharge paths are within coalescing range.

55 4. An apparatus according to any preceding claim in which the first and third electrodes are adjacent one another and the second and fourth electrodes are adjacent one another.

5. An apparatus according to claim 4 in which the  
60 first and fourth electrodes are connected through a respective impedance to a common terminal and each of the second and third electrodes are connected through a respective impedance to another common terminal, the common terminals being for connection  
65 to a power supply.

6. An apparatus as claimed in any of claims 1 and 3 to 5 in which a respective impedance is connected to each electrode in the power supply path to that electrode.

70 7. An apparatus as claimed in claim 6 in which the impedances are all of substantially the same value.

8. An apparatus as claimed in any preceding claim in which one or more further discharge paths defined by further electrodes may be arranged alongside the first and second discharge paths.

75 9. An electric discharge apparatus substantially as herein described with reference to and illustrated by Figure 1 of the accompanying drawings.

10. A discharge lamp including an electric discharge apparatus as claimed in any preceding claim.

80 11. A discharge lamp as claimed in claim 10 in which the lamp is a fluorescent lamp.

12. A fluorescent lamp substantially as herein described with reference to and as illustrated by Figure 2 or by Figure 3 of the accompanying drawings.

13. A welding apparatus including an electric discharge apparatus as claimed in claim 2.

14. A submerged arc welding apparatus including an electric discharge apparatus as claimed in claim 2.

90 15. A submerged arc surface deposition apparatus substantially as herein described with reference to and as illustrated by Figure 4 of the accompanying drawings.

16. A gas laser including an electric discharge apparatus as claimed in any of claims 1 to 9.

17. A method of generating discharges including the steps of generating a first discharge, and generating a second discharge alongside the first discharge, wherein the current flow in the first discharge is so different from the current flow in the second discharge that, overall, the discharges repel one another.

18. A method as claimed in claim 17 in which the first and second discharges are within coalescing range.

105 19. A method as claimed in claim 17 or 18 including generating further discharges alongside the first and second discharges.

20. A method of generating discharges, the method being substantially as herein described with reference to and as illustrated by Figure 1, or by Figure 2, or by Figure 3, or by Figure 4 of the accompanying drawings.

Amendments to the claims have been filed, and have the following effect:—

115 (a) Claims 1 to 20 above have been deleted or textually amended.

(b) New or textually amended claims have been filed as follows:—

#### CLAIMS

1. A gas laser including a discharge tube in which are provided first and second electrodes defining a first discharge path, and third and fourth electrodes defining a second discharge path alongside the first discharge path, wherein the electrodes are electrically connected such that, in use, discharges are generated simultaneously along both discharge paths and the current flow of a discharge along the first path is so different from the current flow of a discharge along the  
120  
125  
130

second path that, overall, the discharges repel one another.

2. A gas laser according to claim 1 in which the first and second discharge paths are within coalescing  
5 range.

3. A gas laser according to claim 1 or 2 in which the first and third electrodes are adjacent one another and the second and fourth electrodes are adjacent one another.

10 4. A gas laser according to claim 3 in which the first and fourth electrodes are connected through a respective impedance to a common terminal and each of the second and third electrodes are connected through a respective impedance to another common terminal,  
15 the common terminals being for connection to a power supply.

5. A gas laser as claimed in any preceding claim in which a respective impedance is connected to each electrode in the power supply path to that electrode.

20 6. A gas laser as claimed in claim 5 in which the impedances are all of substantially the same value.

7. A gas laser as claimed in any preceding claim in which one or more further discharge paths defined by further electrodes are arranged alongside the first and  
25 second discharge paths.

8. A gas laser including an electric discharge apparatus substantially as herein described with reference to and as illustrated by Figure 1 of the accompanying drawings.

30 9. A method of operating a gas laser, the method including the steps of generating a first discharge, and simultaneously generating a second discharge alongside the first discharge, wherein the current flow in the first discharge is so different from the current flow in  
35 the second discharge that, overall, the discharges repel one another.

10. A method as claimed in claim 9 in which the first and second discharges are within coalescing range.

40 11. A method as claimed in claim 9 or 10 including generating further discharges alongside the first and second discharges.

12. A method as claimed in any of claims 9 to 11 in which a respective impedance is connected to each  
45 electrode in the power supply path to that electrode.

13. A method of operating a gas laser, the method including generating discharges by a method substantially as herein described with reference to and as illustrated by Figure 1 of the accompanying drawings.